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(54) Element for use in optical multiplexer or de-multiplexer

(57) Optical multiplexers and demultiplexers join together, and separate, light of different frequencies particularly so that they can be transmitted down a common optical wave guide. An element for use in a multiplexer or demultiplexer (shown) comprises a transparent dielectric substrate (60) and at least two transmission filters, (11, 12, 13, 14, 15, and 16) each of which transmits light of a predetermined wavelength and reflects light of other wavelengths. The optical filters are arranged so that an optical beam is transmitted or reflected via each optical filter in turn and in a zigzag fashion with light of a particular wavelength being subtracted or added at each filter in dependence of whether the element is being used as a demultiplexer or multiplexer.

When the element is being used as a multiplexer a source of light is provided behind each filter and when the element is used as a demultiplexer a photosensitive detector (71, 72, 73, 74, 75 and 76) is provided behind each filter.

Fig. 12

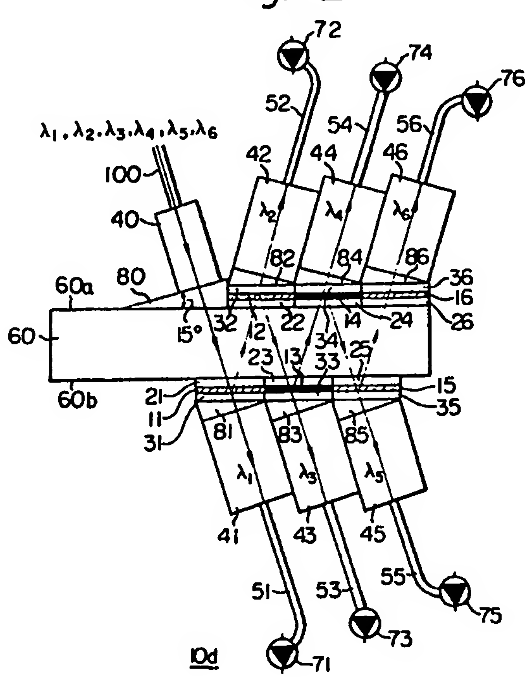

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Fig. 1

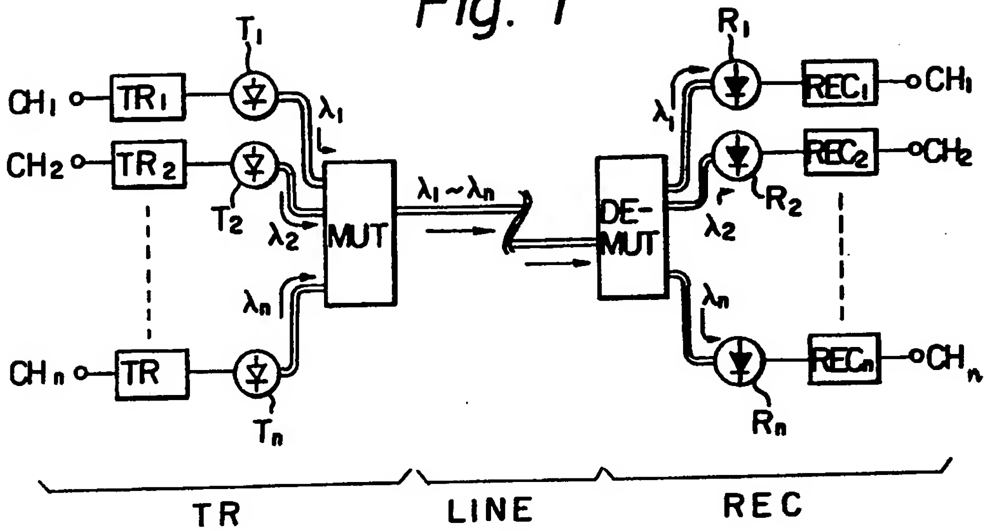

Fig. 4

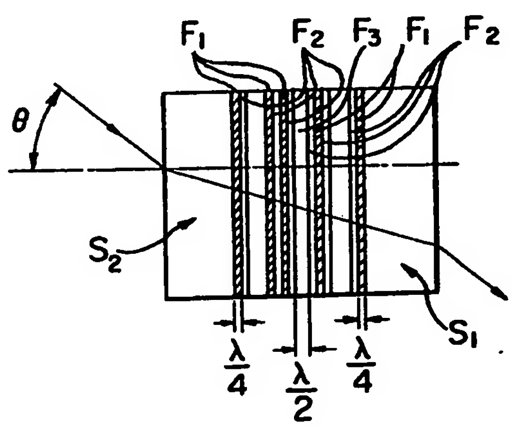

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Fig. 2

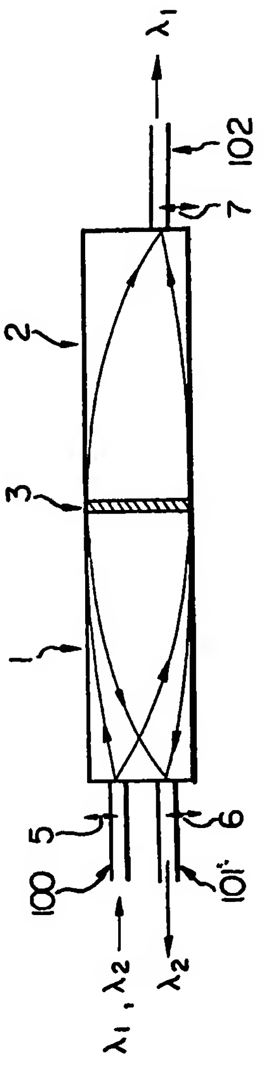


Fig. 3

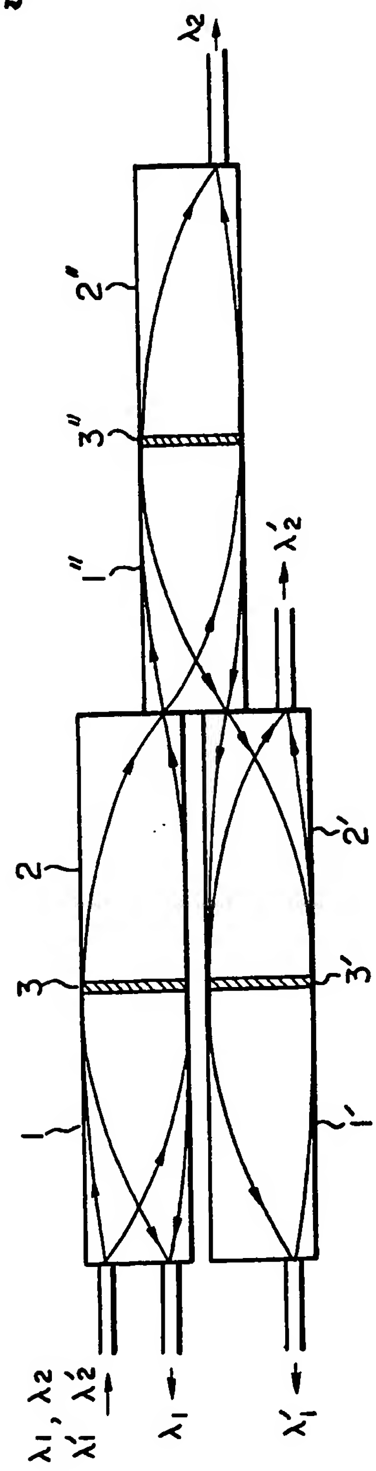
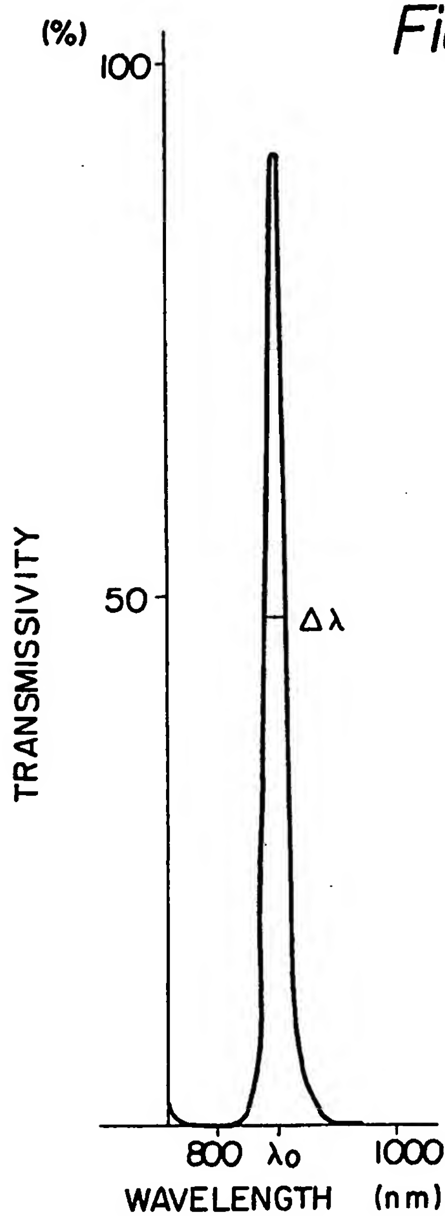


Fig. 5



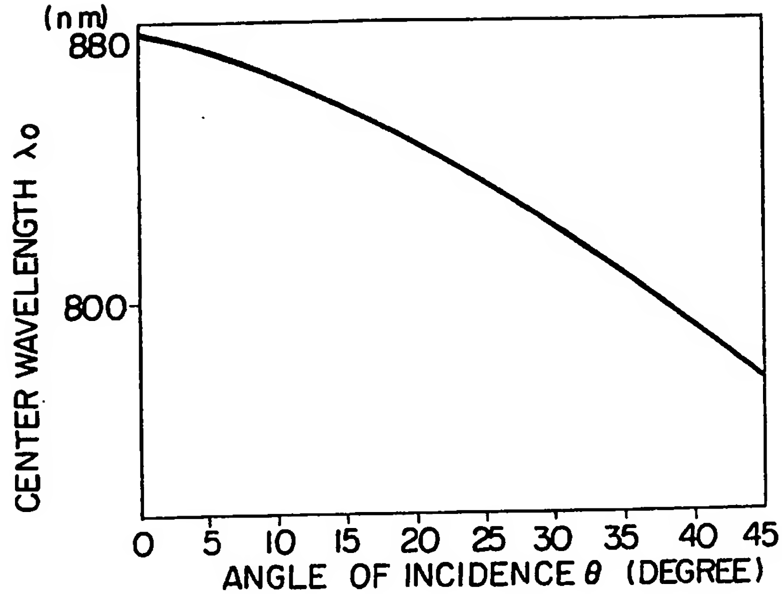


Fig. 6

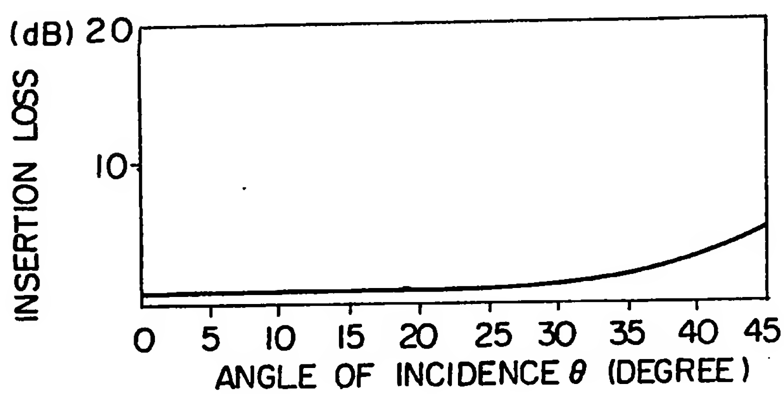


Fig. 7

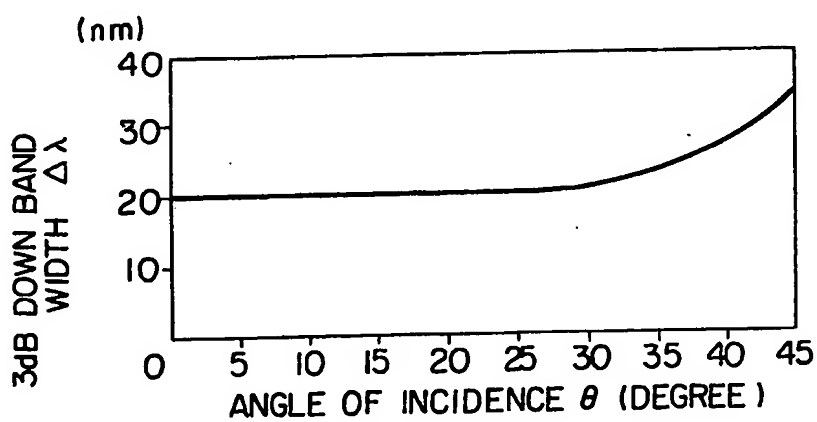


Fig. 8

Fig. 9

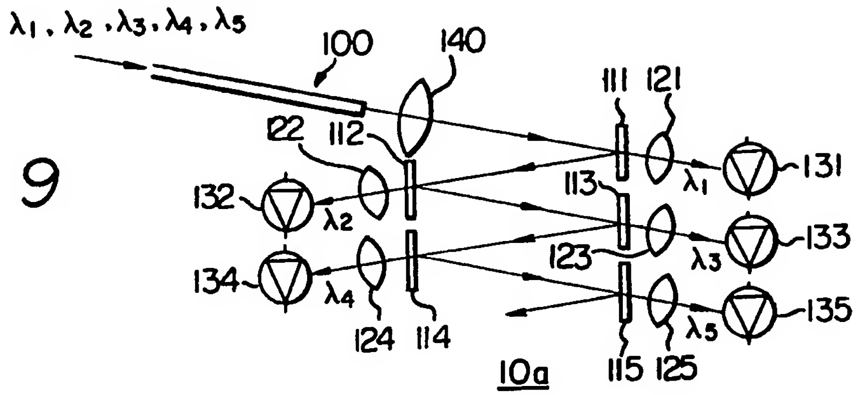


Fig. 10

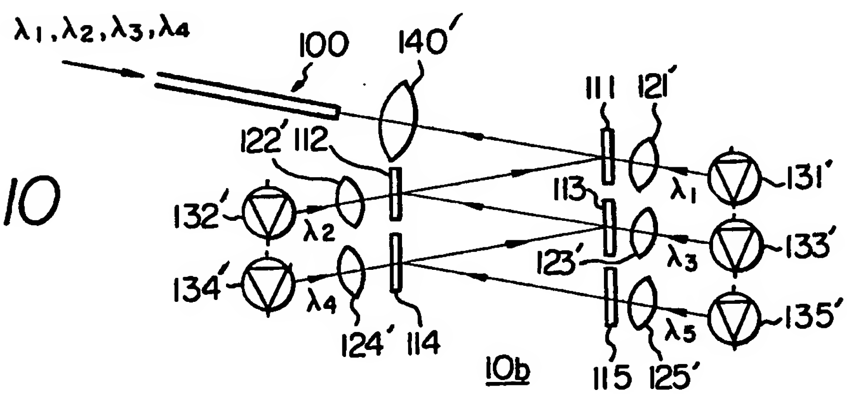


Fig. 11

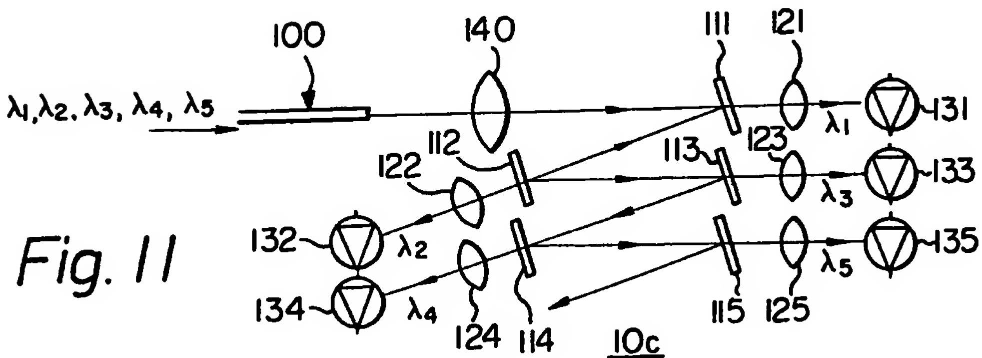


Fig. 12

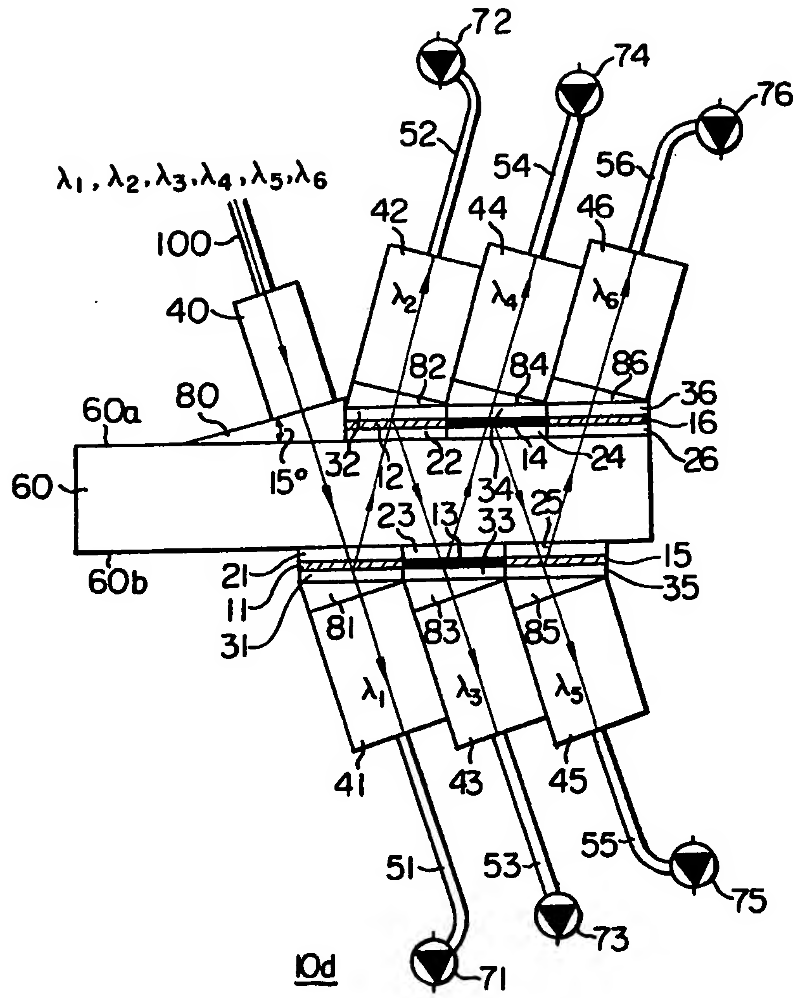

λ1, λ2, λ3, λ4, λ5, λ6
100
40
80
60a
60
60b
15°
72
74
76
52
54
56
42
44
46
λ2
λ4
λ6
82
84
86
36
16
26
32
12
22
14
24
34
23
13
33
25
15
35
21
11
31
81
83
85
λ1
λ3
λ5
41
43
45
51
53
55
71
73
75
10d

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Fig. 13

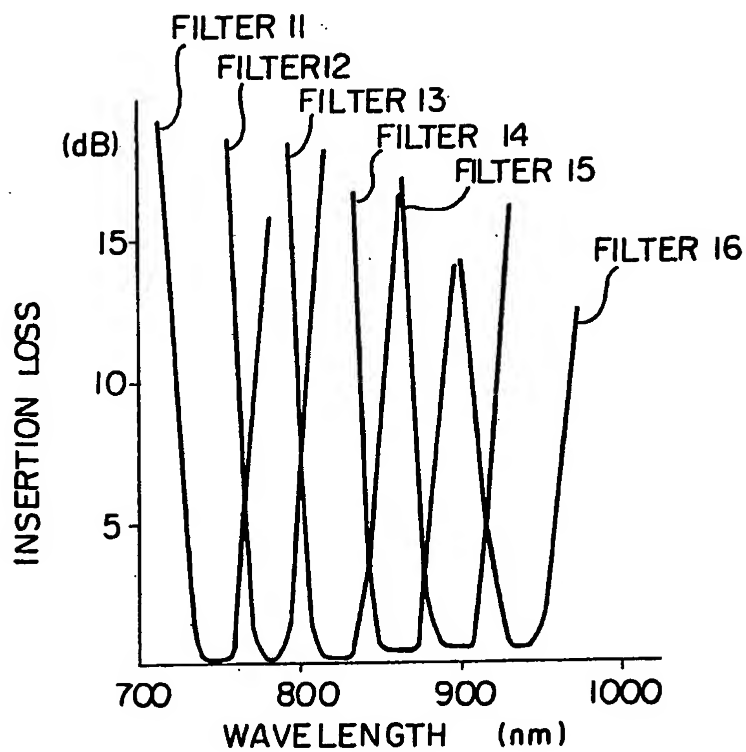

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Fig. 14

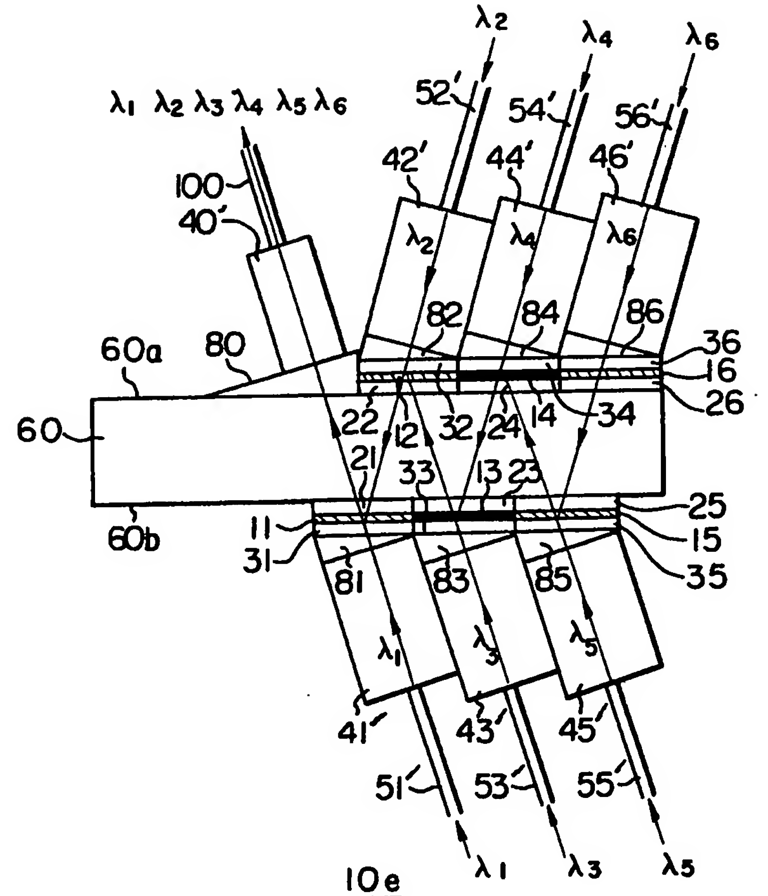
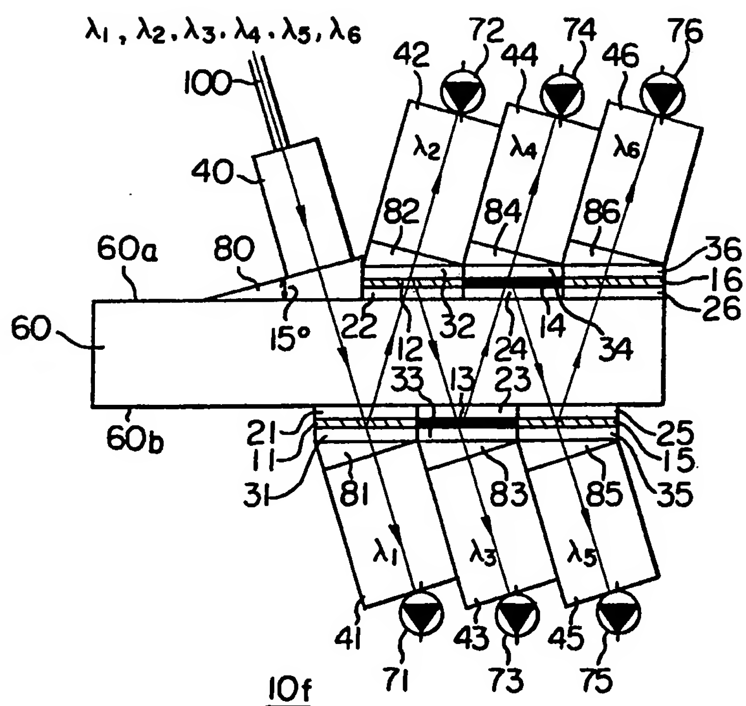


Fig. 15


λ1, λ2, λ3, λ4, λ5, λ6
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42
44
46
72
74
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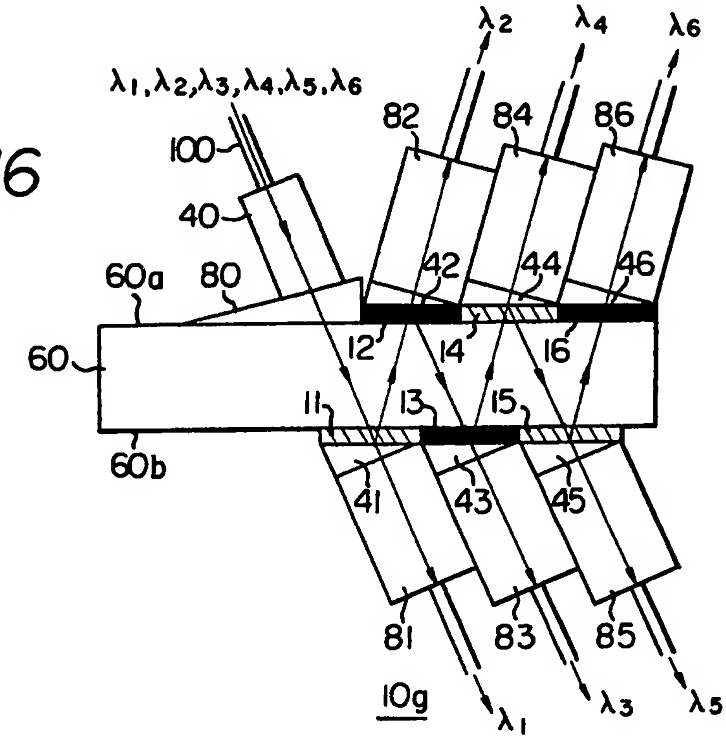
λ2
λ4
λ6
82
84
86
36
16
26
60a
80
15°
22
32
14
34
60
12
24
33
13
23
60b
21
11
31
25
15
35
81
83
85
λ1
λ3
λ5
41
43
45
71
73
75
10f

Fig. 16


λ1, λ2, λ3, λ4, λ5, λ6
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λ4
λ6
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86
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44
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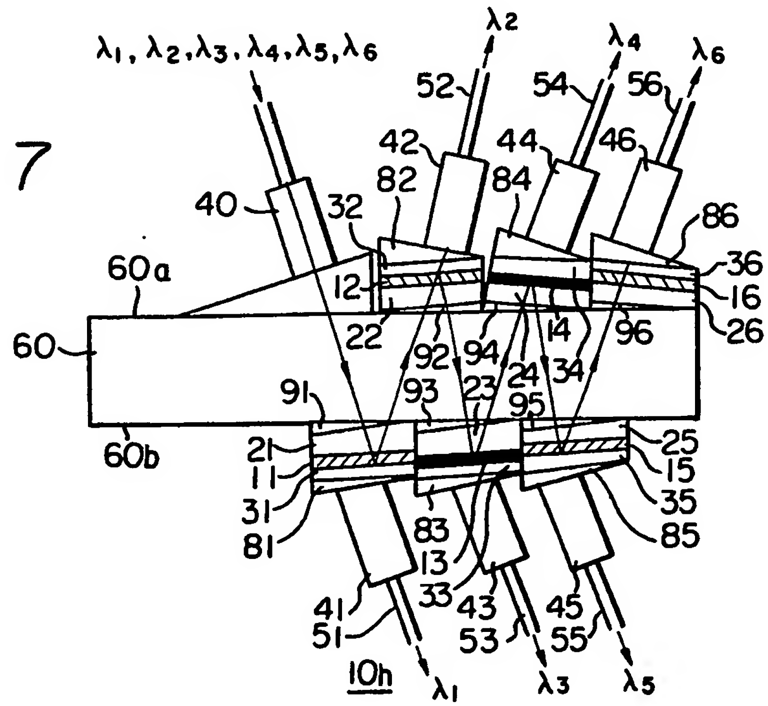
60a
80
60
12
14
16
11
13
15
60b
41
43
45
81
83
85
10g
λ1
λ3
λ5

Fig. 17


λ1, λ2, λ3, λ4, λ5, λ6
λ2
λ4
λ6
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82
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36
16
26
60a
12
22
92
94
14
96
60
91
93
23
24
34
95
60b
21
11
31
81
83
13
33
43
25
15
35
85
41
51
53
45
55
10h
λ1
λ3
λ5

SPECIFICATION

Improvements relating to optical multiplexers and de-multiplexers

The present invention relates to optical multiplexers and demultiplexers which are used for example in spectroscopic analysis equipment, and for the combination and separation of optical signals in wavelength-division multiplexed communication transmission systems.

A telecommunication system using an optical fibre transmission system has advantages over prior metallic cables, such as low loss, wide bandwidth, small cable diameter, light-weight, high-flexibility cable, low cross talk interference, and immunity from electromagnetic interference. The most recent developments in the manufacture of optical fibre with low loss and their light sources, has made wavelength-division multiplexing possible so that a plurality of wavelengths each with different information may be transmitted simultaneously through a single optical fibre. This technology not only increases the transmission capacity of an optical fibre, but also makes possible a two-way transmission system and/or simultaneous transmission of a plurality of different signals on a single optical fibre.

Some devices which can be used for an optical multiplexer and de-multiplexer are a prism, a diffraction grating, and a wavelength-selective filter. Prisms and diffraction gratings cause dispersion of light passing through them and hence can be used to separate or recombine light passing through them. A wavelength selective filter transmits light of a specific wavelength and reflects light of other wavelengths. Such filters may be formed by a plastics material loaded with a colouring matter or dye, or by a laminated thin film interference filter in which thin film multi-layers are deposited on a glass substrate by a vacuum evaporation process.

One previously proposed system using graded index rod lenses and transmission filters will be described in more detail later and contrasted with the present invention.

Another prior optical multiplexer utilising a wavelength selective mirror is disclosed in the United States Patent specification No 3,953,727. According to this specification a de-multiplexer comprises plurality of selective mirrors oriented at 45° in relation to the axis of the light beam and arranged in a cascade configuration with each selective mirror reflecting light of a specific wavelength. Accordingly, when there are many wavelengths to be multiplexed or de-multiplexed the light beam must pass through many reflective filters and therefore the transmission loss is great. Further, the multiplexer described in this specification has the disadvantage that when the wavelength to be separated is near to that of the other components, separation is impossible since the angle of incidence is 45°, and the transmission and/or reflection characteristics of the reflection filters at this angle depends upon the state of polarisation of the light beam. This United States Patent Specification also discloses a multiplexer in which a plurality of band pass filters are arranged around a glass plate having semi-refractive walls. However this multiplexer has the disadvantage that the loss of the light beam is great since the light beam suffers from a plurality of partial reflections and partial transmissions at the semi-reflective walls.

According to one aspect of this invention an element for use in an optical multiplexer or de-multiplexer comprises a transparent di-electric substrate having at least two transmission filters mounted on it which transmit light of different wavelengths, an exit or entrance window, the transmission filters each transmitting light having wavelengths within a particular band and reflecting light having wavelengths outside that band, the transmission filters and the exit and entrance window being arranged so that polychromatic light entering the window and falling on the first of the transmission filters is reflected from this onto the second and any subsequent transmission filters in turn.

According to another aspect of this invention, an optical multiplexer comprises such an element having a source of light located behind each transmission filter and means to provide a substantially parallel beam of light from each source and to couple each source of light to its associated filter, each transmission filter and source of light being matched so that light from each source is transmitted through its associated filter and then passes through the exit window with light from the other sources, the light transmitted by the second and subsequent filters being reflected from one or more filters in turn on passage to the exit window.

According to a further aspect of this invention an optical demultiplexer comprises such an element having a detector located behind each transmission filter and means to couple light transmitted by each transmission filter onto its associated detector so that light transmitted through the entrance window impinges on the first transmission filter where a component is transmitted by the first transmission filter and is detected by its associated detector, and the remainder is reflected from the first transmission filter to the second transmission filter where a second component is transmitted by the second filter and is detected by its associated detector and again the remainder is reflected.

A number of examples of optical multiplexers and de-multiplexers in accordance with this invention will now be described and contrasted with the prior art with reference to the accompanying drawings; in which:-

Figure 1 is a diagram showing the general configuration of a wavelength division multiplex communication system;

Figure 2 illustrates one example of prior art;

Figure 3 illuatrates another example of the prior art;

Figure 4 is a section through a multi-layer di-

electric thin film filter;

Figure 5 is a graph illustrating the transmission characteristics of the filter shown in Figure 4;

Figure 6 is a graph illustrating the relationship between the centre wavelength transmitted by the filter and its angle of incidence for the filter shown in Figure 4;

Figure 7 is a graph illustrating the relationship between the angle of incidence and the insertion loss for the filter illustrated in Figure 4;

Figure 8 is a graph illustrating the relationship between the angle of incidence and half width of the filter shown in Figure 4;

Figure 9 is an optical diagram of the present invention applied to a demultiplexer;

Figure 10 is an optical diagram of the present invention applied to a multiplexer;

Figure 11 is an optical diagram of a modification through a demultiplexer;

Figure 12 is a plan of a first example of demultiplexer;

Figure 13 is a graph showing the characteristics of the de-multiplexer shown in Figure 12;

Figure 14 is a plan of a first example of multiplexer;

Figure 15 is a plan of a second example of the de-multiplexer;

Figure 16 is a plan of a third example of de-multiplexer; and

Figure 17 is a plan of a fourth example of de-multiplexer corresponding to the modification illustrated in Figure 11.

Figure 1 shows the basic configuration of a wavelength-division multiplexed transmission system (called W.D.M.). In this figure, the signals of a plurality of channels ($CH_1, CH_2, \ldots, CH_n$) at the transmission side are converted into driving signals for driving light sources by respective transmitter circuits ($TR_1, TR_2, \ldots, TR_n$), and are applied to light sources ($T_1, T_2, \ldots, T_n$). Each light source generates a light beam the intensity of which varies in dependence upon the driving signals and each of the light sources has a different centre wavelength ($\lambda_1, \lambda_2, \ldots, \lambda_n$), and each of the light beams forms a different channel. A laser or a light-emitting diode (LED) may be used as the light source. The light beams from the light sources are applied to an optical multiplexer (MUT) through an optical fibre and are multiplexed or combined therein, then the multiplexed light beams are applied to a single optical fibre transmission line (LINE).

At the reception side, each wavelength is separated from the others by an optical de-multiplexer (DE-MUT), and each separated light beam is applied to a separate light detector or sensor ($R_1, R_2, \ldots, R_n$), which converts the optical signal back to an electrical signal. The electrical signal is applied to a corresponding output terminal as an output channel through a receiver circuit ($REC_1, REC_2, \ldots, REC_n$).

It should be appreciated that, in a two-way WDM transmission sysystem, the light sources and the light detectors are provided at both the transmission side and the reception side.

The present invention is concerned with the optical multiplexers and/or an optical de-multiplexer for such a system. It should be noted that due to the reversibility of a light beam, the structure of the main element in an optical multiplexer is the same as that of an optical de-multiplexer. Accordingly, it should be noted that the words "multiplexer" or "de-multiplexer" are frequently interchangeable.

A graded index rod lens has a radial profile of the refractive index as given by:-

$$N(r)=N_0(1-(A^2/2)r^2)$$

where n(r) is the refractive index of the rod at a point having a radius r, N_0 is the refractive index at the centre of the rod, A is a constant, and r is the distance from the centre of the rod. When a light beam is applied axially to the centre of such a rod lens the diameter of the beam changes periodically, and when a light beam is applied to a portion other than the centre of the rod, the light beam propagates along the rod in a zigzag fashion. The combination of the above characteristics of a rod lens and a thin film interference has been used in the past to provide an optical multiplexer or de-multiplexer.

This optical de-multiplexer has a structure as shown in Figure 2, in which an interference filter 3 is sandwiched between a pair of graded index rod lenses 1 and 2. The light beam coming into the graded index rod lens proceeds in a zigzag fashion through the graded index rod lens as shown by the lines and arrows. When used as an optical de-multiplexer, the lengths of the graded index rod lenses 1 and 2 are approximately 1/4 of the pitch of the zigzag. The thin film interference filter 3 is made of di-electric multi-layers with a wavelength dependency characteristic, that is, reflectivity and transmissivity of this differs for different wavelengths of light.

Light of two different wavelengths λ_1, and λ_2 is introduced into an optical fibre 100, and is separated by the de-multiplexer into two different beams. The optical signal waves of the two different wavelengths emitted from the optical fibre 100 proceed in a zigzag course through the lens 1 enter the interference filter 3. Then, the interference filter 3 reflects the optical signal wave with wavelength λ_1 but transmits the optical signal wave with wavelength λ_2. The reflected optical signal wave with wavelength λ_1 then emerges from a different position on the input face and enters the optical fibre 101. The optical signal wave with wavelength λ_2 propagates through the graded index rod lens 2 and enters the optical fibre 102. Therefore the two optical signal waves with different wavelengths are separated. The positions 6 and 7 of the optical fibres 101 and 102 which receive the separated signal waves are determined by the position 5 of the optical fibre 100. Therefore, the optical multiplexer as shown in Figure 2 has the disadvantage that the positions of the fibres 101 and 12 for reception of the waves

cannot be adjusted independently.

When three or more waves are to be separated, the configuration shown in Figure 3 is used. In this case, a plurality of graded index rod lenses 1, 2, 1', 2', 1", 2" are assembled. However, loss will be great if connecting positions of these graded index rod lenses are not controlled with great precision. The larger the number of signal waves to be separated, the greater the adjustment difficulties bearing in mind that the output position of one is dependent upon the input position of the preceding one.

Figure 4 shows the structure of a thin film di-electric multi-layer filter which has a laminated structure comprising a number of alternate layers F_1 and F_2, a single layer of F_3, and a further number of alternate layers of F_1 and F_2. The layer F_1 is made of Zinc Sulphide ZnS and has the thickness a quarter of a wavelength $\lambda/4$, the layer F_2 is made of Magnesium Flouride MgF_2 and has the thickness a quarter of a wavelength $\lambda/4$, and the layer F_3 is made of Zinc Sulphide ZnS and has the thickness of half a wavelength $\lambda/2$. Preferably, two groups of alternate layers of F_1 and F_2 have about ten layers of each layer. The first group of layers may be deposited on a glass substrate S_1, and the surface of other group of layers is covered with a protective layer or cover glass S_2. Such a thin film di-electric multi-layer filter has a narrow pass band characteristic in which a small group of wavelengths are transmitted whilst all other wavelengths of light are reflected. The pass band of such a filter is controlled by varying the thickness of the layers F_1, F_2 and F_3 to match their thickness to that of the wavelength which it is required to transmit. When a beam of light is applied to such a filter obliquely the pass-band or the centre wavelength transmitted is determined in accordance with the thickness of the layers in the direction passage of the light beam. Therefore, the pass-band for an oblique light beam is different from that for a normal light beam. The present invention uses such filters with light beams which are not normal but which have a small angle of incidence.

Figure 5 illustrates a typical transmission characteristic of a thin film di-electric multi-layer filter. The horizontal axis indicates wavelength and the vertical axis transmission. In this example, the centre wavelength λ_0 is 875 nm, and the half width $\Delta\lambda$ of the transmitted beam is 20 nm.

Figure 6 shows how the centre wavelength λ_0 of the filter varies with the angle of incidence of the light beam. As is apparent from Figure 6, the larger the angle of incidence θ the more the centre wavelength λ_0 shifts towards the shorter wavelengths.

Figure 7 illustrates an example of the relationship between the insertion loss at the centre wavelength λ_0 and the angle of incidence θ of the filter. Figure 8 shows how the half width increases with large angles of incidence.

Thus, when the angle of incidence θ is selected at less than about 20°, the insertion loss and the half width $\Delta\lambda$ remain substantially the same as those for normal incidence (θ=0°), although the centre wavelength λ_0 is shifted towards the shorter wavelengths.

Figure 9 shows a de-multiplexer 10*a* which comprises a plurality of thin film di-electric multi-layer filters 111, 112, 113, 114 and 115 each of which is similar to that described with reference to Figure 4, a plurality of condenser lenses 121, 122, 123, 124 and 125, a plurality of photo-electric conversion elements (light detectors or sensors) 131, 132, 133, 134 and 135, and a collimating lens 140. The filter array composed of the optical filters 111, 113 and 115 is arranged to be parallel with another filter array composed of the optical filters 112 and 114. Among the optical signal waves to be de-multiplexed, only the optical signal wave with wavelength λ_1 is transmitted through the optical filter 111, which reflects all other wavelengths. Next, the optical filter 112 transmits only the optical signal wave with wavelength λ_2 and reflects all other wavelengths. In the same manner, the optical filters 113, 114 and 115 transmit optical signal waves with wavelengths λ_1, λ_2, λ_3 respectively. Thus the present invention separates or combines wavelengths through an array of a plurality of filters with different pass bands.

Now, the operation of the present invention will be described in detail.

Supposing that optical signal waves composed of different wave lengths λ_1, λ_2, λ_3, λ_4, λ_5, are emitted from an optical fibre 100, and are collimated through the collimator lens 140, then, the collimated light beam enters the optical filter 111. According to the characteristics of the optical filter 111, the optical signal wave with wavelength λ_1 is transmitted through the optical filter 111, while optical signal waves of other wavelengths are reflected onto the optical filter 112. The optical signal wave having a wavelength λ_1 which is transmitted through the optical filter 111 is focused by the condenser lens 121 onto the light detector 131. Similarly, among the light beam that enter the optical filter 112 the optical signal wave with a wavelength λ_2 is transmitted through the optical filter 112 and is collimated by the condenser lens 122, which illuminates the light detector 132. The optical signal waves with other wavelengths are reflected by the filter 112 onto the optical filter 113. Similarly, all other optical signal waves are separated in turn by the remaining optical filters. Although the example shown in Figure 9 consists of five optical filters, more filters of dfifferent transmission wavelength bands may be added so that more optical signal waves can of course be de-multiplexed.

Figure 10 shows an example of an optical multiplexer 10*b*, in which signal light sources 131', 132', 133', 134' and 135' generates signals of wavelengths λ_1, λ_2, λ_3, λ_4, λ_5 respectively. Collimating lenses 121', 122', 123', 124' and 125' provide parallel light beams coupling the corresponding light sources with transmission filters 111, 112, 113, 114 and 115. A condenser lens 140' connects the multiplexed

optical signals to an output optical fibre 100. An optical signal wave with a wavelength λ_1 generated by the source 131 passes through the optical filter 111, is collimated by the condenser lens 140′ and is then introduced into the optical fibre 100. An optical signal wave with a wavelength λ_2 generated by the source 132′ passes through the optical filter 112, is reflected from the optical filter 111, is collimated by the condenser lens 140′, and is introduced into the optical fibre 100. Similarly, the light beams with wavelengths λ_3, λ_4, and λ_5 from the sources 133′, 134′ and 135′ are introduced into the optical fibre 100 after reflections from various of the filters.

Figure 11 illustrates a modified demultiplexer 10*c* in which each array of optical filters are not arranged in a straight line. Instead, each filter is placed at an angle to a line connecting them. With this arrangement, the multiplexing and/or the demultiplexing is performed in a similar manner as described with reference to Figures 9 and 10.

Figure 12 shows the detailed structure of an optical demultiplexer 10*d*. In this Figure, the reference numerals 11, 12, 13, 14, 15 and 16 indicate thin film dielectric multi-layer optical band pass filters, numerals 21, 22, 23, 24, 25 and 26 indicate glass plates which support the optical band pass filters and numerals 31, 32, 33, 34, 35 and 36 indicate glass protectors for protecting the optical band pass filters. Reference numeral 40 indicates a graded index rod lens for collimating light from an optical fibre 100, numerals 41, 42, 43, 44, 45 and 46 indicate graded index rod lenses for focussing light beams, numerals 51, 52, 53, 54, 55 and 56 indicate optical fibres for guiding the demultiplexed light to light detectors or the sensors 71, 72, 73, 74, 75 and 76 and numeral 60 indicates a transparent common substrate having parallel planes 60*a* and 60*b*. Prisms 81, 82, 83, 84, 85 and 86 couple oblique incident light beams passing through the optical filters to the graded index rod lenses. Prism 80 is positioned between the plane 60*a* of the substrate and the fibre 100 and has a similar angle to the other prisms. The vertical angle of the prisms 80 through 86 is the same as the angle of incidence of the optical beams to the optical filters, and this angle is 15 degrees. A group of filters comprising the optical band pass filters 11, 13 and 15 and another group of filters comprising the optical band pass filters 12, 14 and 16 are lined up on the parallel surfaces 60*a* and 60*b* of the common substrate 60. Further it should be appreciated that the refractive indices of the glass plates 21, 22, 23, 24, 25 and 26, the glass protections 31, 32, 33, 34, 35 and 36, the common substrate 60, and the optical fibres 51, 52, 53, 54, 55, 56 and 100 are substantially equal and are matched to that of the graded index rod lenses 40, 41, 42, 43, 44 and 45. Since these components are in optical contact and their refractive indices are approximately equal, the reflection at the interface junction of the components is negligibly small. The centre wavelength of the band-pass optical filter 11 is λ_1, thus a light beam with wavelength λ_1 passes through the band-pass optical filter 11. However, other wavelengths λ_2, λ_3, λ_4, λ_5, λ_6 which are sufficiently apart from the wavelength λ_1 are reflected by the filter 11. Similarly the centre wavelengths of the optical band-pass filters 12, 13, 14 and 15 which are λ_2, λ_3, λ_4, λ_5, λ_6 respectively, reflect light beams which are apart from their respective centre wavelengths.

Now the operation of the device shown in Figure 12 will now be described. When light waves with wavelengths λ_1, λ_2, λ_3, λ_4, λ_5, λ_6 are applied to the rod lens 40 from the optical fibre 100, these light waves are collimated by the lens 40 to form parallel beams and enter the optical band-pass filter 11 with the oblique incidence angle defined by the vertical angle of the prism 80. The angle of incidence of the filter is 15 degrees. According to the characteristics of the optical band-pass filter 11, a light wave with the wavelength λ_1 is transmitted through the optical band-pass filter 11. Other waves are reflected by the optical band-pass filter 11 and enter to the second optical band-pass filter 12 through the glass plate 21, the common substrate 60 and the glass plate 22. The light of wavelength λ_1 which is transmitted by the filter 11, passes through the prism 81, and the rod lens 41, and enters the optical fibre 51, which guides the light wave of wavelength λ_1 to the sensor 71. An electrical signal related to the intensity of the light of wavelength λ_1 is obtained at the output of the sensor 71. Next, among the light beams which are reflected by the optical band-pass filter 11 and enter the second optical band-pass filter 12, only the light wave with the wavelength λ_2 is transmitted by the second optical band-pass filter 12, through the prism 82, the rod lens 42 and the optical fibre 52 and is applied to the sensor 72. The sensor 72 provides an electrical signal related to the intensity of the light having a wavelength λ_2 at the output of the sensor 72. The light beams having wavelengths of λ_3, λ_4, λ_5, λ_6 are reflected by the second optical band-pass filter 12 and enter the third optical band-pass filter 13 through the glass plate 22, the common substrate 60 and the glass plate 23. In an analogous way the light waves with wavelengths λ_3, λ_4, λ_5 and λ_6 are separated in sequence through the optical band-pass filters 13, 14, 15 and 16 respectively. Although six optical band-pass filters are disclosed in this example more light waves can be demultiplexed with arrangements having more filters each with a different centre wavelength.

Figure 13 shows the demultiplexing characteristics of the demultiplexer 10*d* discribed with reference to Figure 12. In the figure, the horizontal axis indicates wavelength and the vertical axis shows the insertion loss provided in passing through the optical band-pass filters 11 through 16. Said insertion loss is defined by the following formula:

$$-10\log\left[\frac{\text{(output power from a specified filter)}}{\text{(Input power to the demultiplexer)}}\right]$$

It should be appreciated from Figure 13 that the light waves of centre wavelengths from respective filters are emitted with low loss, but the light waves with wavelengths apart from the centre wavelengths are substantially not emitted.

The embodiment illustrated in Figure 12 is an example of a demultiplexer, and it should be appreciated that a similar arrangement as that in Figure 12 can be used as an optical multiplexer to combine a plurality of wavelengths in a single optical fibre.

Figure 14 shows an optical multiplexer. In the figure, the reference numeral 40′ indicates a graded index rod lens for coupling an optical beam to a transmission optical fibre 100 from the multiplexer 10*e*. Numerals 41′, 42′, 43′, 44′, 45′, and 46′ are graded index rod lenses which collimate light to be multiplexed from optical fibres 51′, 52′, 53′, 54′, 55′, 56′ into parallel beams of light which are applied to a commom substrate 60 at an oblique incident angle through optical band-pass filters. These collimated beams propagate in the opposite direction to the example shown in Figure 12, and the collimated beams enter into the rod lens 40′, which couple the multiplexed beams to the transmission optical fibre 100.

As an example, a light wave with a wavelength λ_2 is guided by the optical fibre 52′, is collimated into a parallel beam by the collimating rod lens 42′ and then is applied to the optical band-pass filter 12 with an oblique incident angle through the prism 82. The beam passes through the filter 11, the glass substrate 22, the common substrate 60 and the glass substrate 21. The beam of light with a wavelength λ_2 is then reflected by the filter 11 through the substrate 21, and 60, through the prisms 80 the rod lens 40′ and into the fibre 100.

Similarly the light beams of the wavelengths λ_3, λ_4, λ_5, λ_6, are reflected by the optical band-pass filter 12 and join the light beam having the wavelength λ_2. The optical band-pass filter 11 also transmits light of wavelength λ_1, so that this also passes through the substrate 21, 60, the prism 80 and into the transmission optical fibre 100.

Figure 15 illustrates another example of demultiplexer 10*f* and the same reference numerals are used for components which are the same as in the example shown in Figure 12. The important difference of this example is that the demultiplexed beams do not enter an optical fibre but are applied directly to the light detectors of sensors 71, 72, 73, 74, 75 and 76 positioned at the end of the rod lenses 41, 42, 43, 44, 45, 46.

Figure 16 illustrates another example of demultiplexer and again it is generally similar in construction and use to that described in Figure 12 and once again the same reference numerals apply. The important difference shown in Figure 16 is that the thin di-electric multi-layer filters 11, 12, 13, 14, 15 and 16 are directly formed on the surface of the prisms 81, 82, 83, 84, 85, 86 or on the surface of the common substrate 60 by a vacuum evaporation or sputtering process. Therefore, no glass plate or glass protection is provided in this example. A multiplexer may be constructed in an exactly analogous fashion.

It should be noted as indicated in Figure 6, that the centre wavelength λ_0 of an optical band-pass filter can be adjusted by controlling the angle of incidence of the input light beam. By utilising this characteristic, when the centre wavelength of an optical band pass filter has some deviation from the desired value because of an error in the manufacturing process, fine adjustment of the centre wavelength of a band-pass optical filter is possible.

Figure 17 illustrates a further example of a demultiplexer in which adjustment of the centre wavelength of the filter may take place. Where relevant, the same reference numerals as those in Figure 12 are used. The important feature of the example in Figure 17 is the presence of a second group of prisms 91, 92, 93, 94, 95 and 96 which provide fine adjustment of the angle of incidence of the light beam at each filter. The vertical angles of these prisms 91, 92, 93, 94, 95 and 96 are designed so that their respective optical band-pass filters 11, 12, 13, 14, 15, 16 have optimum angles of incidence. The sum of the vertical angles of the first group of prisms and the second group of prisms is substantially equal to the angle of incidence of a light beam to optical filters. It should be appreciated in the example of Figure 17, that the diameter of each optical band-pass filter is sufficiently larger than the diameter of an applied optical beam so that an optical beam does not extend beyond an optical filter when an angle of incidence is changed.

In the example in Figure 17, even if the centre wavelengths of the optical band-pass filters 11, 12, 13, 14, 15 and 16 have a small deviation due to the manufacturing error from the desired centre wavelengths λ_1, λ_2, λ_3, λ_4, λ_5, λ_6, such errors can be compensated for by adjusting the angle of incidence of an optical beam utilising compensation prisms 91, 92, 93, 94, 95 and 96. Further since the diameter of the optical band-pass filters is sufficiently large, the multiplexing and/or demultiplexing operation is not disturbed even when the angle of incidence of an input light beam changes from the designed angle of incidence.

As described above, a multiplexer and/or a demultiplexer according to the present invention has the advantages listed below.

a) Light beams do not propagate in the air because those elements are optically contacted each other.

b) Thus, an optical multiplexer/demultiplexer free from external thermal disturbances and mechanical vibrations can be arranged, and its size is readily reducible.

c) Multiple signal waves can be multiplexed or demultiplexed with small loss by arranging the optical filters in an array.

d) Signal waves with narrow wavelength separation can be multiplexed of demultiplexed through the use of the optical band-pass filters.

e) The characteristics of the device can be adjusted by adjusting the angle of incidence of a light beam going into the optical band-pass filters.

f) Further, without providing an anti-reflection coating on individual components, a low loss multiplexer or demultiplexer whose size is readily reducible can be formed, because the optical fibres, the lenses, the thin film dielectric filter, substrates and covers, and the common substrate have the same refractive index.

CLAIMS

1. An element for use in an optical multiplexer or de-multiplexer comprising a transparent di-electric substrate having at least two transmission filters mounted on it which transmit light of different wavelengths, and an exit or entrance window, the transmitting light having wavelengths within a particular band and reflecting light having wavelengths outside that band, the transmission filters and the exit and entrance window being arranged so that polychromatic light entering the window and falling on the first of the transmission filters is reflected from this onto the second and any subsequent transmission filters in turn.

2. An optical multiplexer comprising an element according to claim 1, having a source of light located behind each transmission filter and means to provide a substantially parallel beam of light from each source and to couple each source of light to its associated filter, each transmission filter and source of light being matched so that light from each source is transmitted through its associated filter and then passes through the exit window with light from the other sources, the light transmitted by the second and subsequent filters being reflected from one or more filters in turn on passage to the exit window.

3. An optical de-multiplexer comprising an element according to claim 1, having a detector located behind each transmission filter and means to couple light transmitted by each transmission filter onto its associated detector, so that light transmitted through the entrance window impinges on the first transmission filter where a component is transmitted by the first transmission filter and is detected by its associated detector, and the remainder is reflected from the first transmission filter to the second transmission filter where a second component is transmitted by the second filter and is detected by its associated detector and again the remainder is reflected.

4. An apparatus according to any one of the preceding claims, in which each transmission filter is formed by a narrow band di-electric multi-layer filter.

5. An apparatus according to any one of the preceding claims, in which means are provided to enable the angle between each transmission filter and the light incident upon it to be varied so that a particular band of wavelengths transmitted by each filter is varied.

6. An apparatus according to claim 5, in which the means includes a prism.

7. An apparatus according to any one of the preceding claims in which the angle of incidence of the light beam onto each of the transmission filters is substantially 15°.

8. An apparatus according to any one of the preceding claims in which the transmission filters are formed directly upon opposite sides of the substrate.

9. An apparatus according to any one of the preceding claims, in which means are provided at the exit and entrance window to enable the element to be connected to an optical fibre.

10. An optical multiplexer comprising a transparent di-electric substrate having first and second parallel planes, a first group of optical filters positioned linearly on the first plane, a second group of optical filters positioned linearly on the second plane but staggered in relation to the corresponding filters on the first plane, means for projecting collimated optical beams to each of the optical filters with some angle of incidence, means provided at the output of the final optical filter to connect the output optical beam to an outside optical fibre and said optical filters having the characteristic to transmit a wave having a predetermined wavelength and reflect waves having other wavelengths and the transmittable wavelength depending upon each specific optical filter.

11. An optical de-multiplexer comprising a transparent di-electric substrate having first and second parallel planes, a first group of optical filters positioned linearly on said first plane, a second group of optical filters positioned linearly on the second plane but staggered in relation to the corresponding filters on the first plane, means for projecting the collimated optical beam to the first optical filter with some angle of incidence, at least one light detector provided behind each optical filter, and said optical filter having the band-pass characteristic to transmit a wave having a predetermined wavelength and reflect waves having other wavelengths and the centre wavelength depending upon each specific optical filter.

12. A multiplexer according to claim 10 or a de-multiplexer according to claim 11, wherein said means for projecting collimated optical beams to each of the optical filters with some angle of incidence includes a prism.

13. A multiplexer or a de-multiplexer according to claim 12, in which the angle of incidence is substantially 15°.

14. A multiplexer according to claim 10 or a de-multiplexer according to claim 11, wherein said optical filters are directly attached to the parallel surfaces of the substrate through either an evaporation or a sputtering process.

15.An optical multiplexer according to claim 10 or a de-multiplexer according to claim 11, wherein all the optical elements provided in the path of the light beam are in optical contact so that the beam does not pass through air.

16. A multiplexer or a de-multiplexer according to claim 15, wherein all the optical elements

provided along the path of the light beam have approximately the same refractive indexes as each other so that the light beam does not reflect at the contact surface between any two of the elements.

17. An optical multiplexer according to claim 10 or a de-multiplexer according to claim 11, in which a prism is located between the substrate and each optical filter for adjusting the angle of incidence of the light beam on the optical filter.

18. An optical multiplexer comprising at least one flat optical filter which transmits a predetermined wavelength and reflects other wavelengths, said optical filter being arranged so that an optical beam is transmitted or reflected by said optical filter in sequence, an optical means provided behind each optical filter to provide a parallel optical beam from an optical source to each optical filter with a small angle of incidence, another optical means provided at the output of the final optical filter to connect the output optical beam to an optical fibre, and the centre wavelength of each optical filter being different from the others.

19. An optical de-multiplexer comprising at least one flat optical filter which transmits a predetermined wavelength and reflects other wavelengths, said optical filter being arranged so that an optical beam is transmitted or reflected by said optical filter in sequence, an optical means for applying a collimated input optical beam to a first optical filter with a small angle of incidence, another optical means, confronting each optical filter to receive and focus the transmitted beam from each optical filter and to illuminate a light detector, and the centre wavelength of each optical filter being different from the others.

20. An optical multiplexer according to claim 10, wherein said optical filter is a di-electric thin film filter having a band-pass property.

21. An optical de-multiplexer according to claim 11, wherein said optical filter is a di-electric thin film filter having a band-pass property.

22. An optical multiplexer according to claim 18, further comprising means for adjusting the angle of incidence of a light beam to an optical filter to control the centre wavelength of each optical filter, said means being provided for each optical filter.

23. An optical de-multiplexer according to claim 19, further comprising means for adjusting the angle of incidence of a light beam to an optical filter to control the centre wavelength of each optical filter, said means being provided for each optical filter.

24. An optical element for use in an optical multiplexer or de-multiplexer constructed substantially as described with reference to Figures 4 to 17 of the accompanying drawings.

25. An optical multiplexer according to claim 2, constructed substantially as described with reference to Figures 4 to 8 , Figure 10 or Figure 14 of the accompanying drawings.

26. An optical de-multiplexer according to claim 3 constructed substantially as described with reference to Figures 4 to 9, Figures 11 to 13 or Figures 15 to 17 of the accompanying drawings.

27. An optical transmission system including an element, a multiplexer, or a de-multiplexer in accordance with any one of the preceding claims.

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